Development and Application of CAD Software in the Field of Building Structures in China

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Summary

PKPM series CAD software is an integrated CAD system for building design, which integrated the following parts: architectural design, structural design, building service design and statistic analysis of quantity and budget. These four parts share the same database with high efficiency. Over 80% of design corporation in China are using PKPM series CAD software. The detailed information and some key modules of PKPM series CAD software are mainly introduced in this paper.

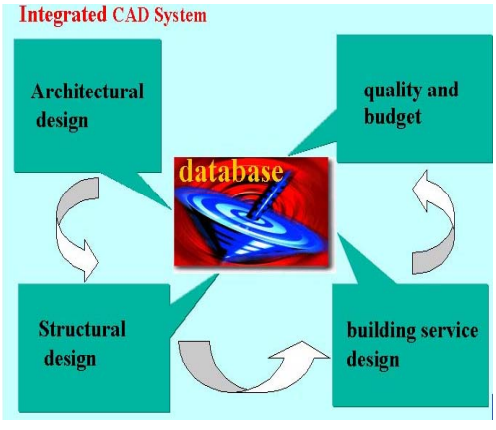
1 Introduction

According to the technical level, three generations of CAD software are/will developed. Before 1985, the CAD software of first generation was developed. It was primary CAD software with lower technical level, where the input of structural information was mainly based on text files, less interactive or graphic technique was used. The most important features of the CAD software of second generation are 2D and 3D based interactive input, integrated, and advanced, but without artificial intelligence. The CAD software of second generation is widely used today. The key difference of the CAD software of second generation and third generation is without or with artificial intelligence. The CAD software of third generation (it is of 21 century) will be AI based and Internet based.

The CAD Software currently used in China is mainly developed in China （CABR）, Such as PKPM of CABR, TUS of Qinghua University, etc. There are about 11,000 design corporation in China. Over 80% of them are using PKPM series CAD software. It can be said that PKPM is the representation of CAD software in China. So, here it will be mainly introduced the development and application of PKPM series CAD software in China.

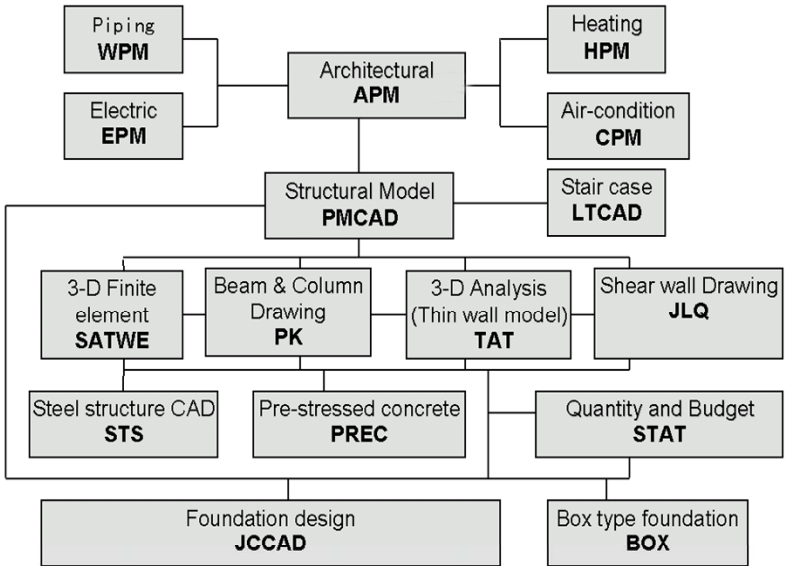
2 Family of PKPM CAD Series

2.1 Integrated CAD system



PKPM series CAD software is an integrated CAD system for building design, which integrated the following parts: architectural design, structural design, building service design and statistic analysis of quantity and budget. These four parts share the same database with high efficiency. From the design of the architecture, a common database of the whole building is established. All the data could be used in the following structure design. The loads of decoration material and wall-enclosure material can be created automatically. After statistic analysis and transmitting calculation of loads, a database of the loads is provided automatically for the design of upper-structure and foundation structure.

Instead of complicated manual work, condition drawings of service design can be created automatically. Thus, the correctness and efficiency can be improved greatly. The family chart of PKPM CAD system is shown as follows.



2.2 With a powerful graphic platform

This system is based on a powerful graphic platform (CFG), which is specially and independently developed for CAD software of buildings by PKPM department. On the one hand, CFG is similar to AutoCAD R14, which has strong functions of graphic management, edit, and interactive input of architectural and structural model. On the other hand, CFG is different from generally purposed graphic platforms, which embeds into professional CAD software. So, it has some special characteristics, such as convenient to use, with plenty of professional functions and with high degree of adaptability.

2.3 With a powerful model builder

A distinctive interactive input method is adopted. It is not necessary for the users to prepare the tedious data document like before. Under the direction of the menus, users can sketch the whole building with mouse or keyboard. The plenty and ripe graphic input functions make the input tasks more efficient. It has been proved that designers can master this system more easily, and the efficiency might be ten times higher than those of traditional methods.

In the part of architectural design (APM), after establishing the database of building model by 3D interactive input method, users can observe the perspective model and ramble in it freely. The working drawings of the plan, elevation, section and prospective view of the building can be obtained more quickly and conveniently from the database. Rendering and animation can also be achieved with high efficiency. APM can be operated in relay with the structural CAD software and building service CAD software in this system, and the database can be shared.

Statistic analysis and transmitting calculation of loads is the most important function in structural CAD software. The loads can be calculated and transmitted automatically from slabs to beams, from beams to girders and also from upper-structure to the foundation.

2.4 With a set of popular analysis methods for structural design

A set of popular analysis methods of structures are provided in structural part, which are as follows:

(1) advanced three dimensional finite element analysis (SATWE)
(2) three dimensional thin-wall column system (TAT)
(3) two dimensional frame and continuous beam calculation (PK)
(4) two dimensional high-accuracy finite element calculation (FEQ)
(5) elastic dynamic analysis of tall buildings (TAT-D)
(6) staircase with beam slabs, cockle-stair and cantilever-stair (LTCAD)
(7) independent foundation, strip foundation, elastic beam foundation, raft foundation and pile foundation (JCCAD), and box foundation (BOX)
(8) rectangular and irregular slab calculation and anti-seismic calculation for brick-concrete structures (PMCAD)

It reflects wholly the requirements of load design code, anti-seismic design code, and design codes of reinforced concrete structure, of steel structure and of composite structure of steel and reinforced concrete.

There are lots of advanced functions for the working drawings of RC structures and steel structures. By means of this system, the working drawings of structures such as beams and columns of frame, continuous beam, structural plan, reinforcement of floor slabs, details of joint, different foundations, staircases, shear walls, and etc. can be performed. It has unique characteristic in automatic selection of reinforcement for different stories, bays and cross-sections, and flexible arrangement of drawings.

2.5 CAD software for building service

Building service design includes five modules, which are as follows:

(1) heating service design (HPM)
(2) air-condition and ventilation design (CPM)
(3) electric service design (EPM)
(4) water service design of inside and outside of buildings (WPM, WNET)
(5) compatibility and consistency checking of buildings (Building Checking)

The conditional drawings and data can be created either by means of APM or by AutoCAD. Plug-sets and pipe-wires can be arranged interactively.

2.6 Application of the software

PKPM series CAD software is composed of several modules, which can be used together or separately. Here is the family chart of these modules. It is the most popular software in China, which got the awards of Nationwide Bronze Medal (1996) and Silver Medal (1999) of Science and Technology Progress, respectively. The clients of it have exceeded 9,000 in China. It is also very popular in Southeast Asian countries and district, such as Singapore, Malaysia, Vietnam, and Hong Kong. In order to meet the requirement of the clients of different countries, a set of special versions of PKPM series CAD software with English interface are developed, which are as follows:

CHN Version ____ for users using Chinese design codes
BS Version ____ for users using British standards
HDB Version ____ for users of Singapore
HK Version ____ for users of Hong Kong

The HDB Version is cooperatively developed with HDB of singapore, where some functions are specially developed for HDB, such as loading plan, loading intensity, slab mesh, PC plank, beam cage, column cage, RC wall, facade, pile cap, etc.

This system has been approved by the China Software Association and registered in the register center. The register number is 920074. It is protected by the Software Protecting Rules. As the well-developed commercial software, it has a perfect after-sell service system. Clients training, technical support, and version maintenance are all guaranteed. Version updating periodically makes the system win its high reputation.

3 Structural CAD software of PKPM

3.1 CAD software of structural model and plan (PMCAD)

PMCAD is the base of the structural part of PKPM series CAD Software. By using the interactive graphical model builder, All information of the structural plans, including the arrangement of beams, columns, bearing walls, secondary beams, precast slabs, openings, cantilevered eaves and external loads, etc., can be inputted storey by storey, and then the floor heights are inputted to establish the database the building structure. It can provide necessary data for the subsequent design with the database. During the process of interactive input, functions for interruption at any time, modification, copy, printing, consulting and continuous operation are provided. The operation of PMCAD is simple, and the efficiency of data interactive input is high. The data for structure design can be created conveniently by PMCAD.

PMCAD has strong functions of loads calculation and transmission. the external Loads, as well as the weight of the structure, can be calculated and transmitted from floor slabs to beams, then from beams to columns and bearing walls, from upper-structures to foundations automatically.

Plotting structural plans of the frame, frame-shear wall, shear wall and brick-concrete structures, including arrangement of columns, beams, walls and openings. the dimensions can be marked. Plotting of eccentric axes and other axes and general dimension, arrangement of precast slabs, secondary beams and openings in floor can also be carried out. Internal force and amount of reinforcement in cast-in-site floor slab can be calculated, and drawing of the arrangement of reinforcement in the slab can be plotted, the detailed working drawings of the joint connecting the ring beam and the constructional column in brick-concrete structures can be performed.Checking of the anti-seismic design of brick-concrete structures and structures with frame in first storey and brick structure in upper-stories can be done.

Statistics for the mount of materials of a structure (such as the amount of concrete or steel bar) can be made and output in the form of table. PMCAD is the required interface software for CAD of shear wall and staircase, 3-dimensional analysis of tall buildings and of various kinds of foundation.

3.2 Three dimensional finite element analysis and design program of building structures (SATWE)

SATWE is a three-dimensional finite element analysis and design program. It is specially developed for the analysis and design of building structures. It can be used in the analysis and design of reinforced concrete tall and multi-storied frame structures, frame and shear wall structures, shear wall structures, and high rise of steel structures or composite structures of steel

and concrete. Special structural features such as multi-tower, stagger floor, transferring floor, and large openings in slab in building structures are rationally considered in SATWE.

The key in the analysis and design of building structures is reasonable simplification of shear walls and slabs. By introducing two super elements --- generalized-wall-element and elastic-slab-element to simulate the shear walls and slabs of building structures, the structural modeling in SATWE is rational and with high efficiency. In the case of the same condition and parameters, SATWE has the same precision with Super SAP, but the efficiency of SATWE may be ten times higher than that of Super SAP.

Generalized-wall-element, condensed from shell element based on the theory of sub-structure, is specially introduced to model the shear walls of building structures. It has as many features of shear walls as possible, has no limitation to the arrangement and size of shear walls and openings, has less freedom of degrees and has high precision. It can reflect the real stress and strain states better. Similar to the generalized-wall-element, elastic-slab-element is specially formed to model the slabs of building structures. In order to reduce freedom of degrees further, a set of additional simplified assumptions are given in SATWE as follows: infinite rigidity in-plane in a whole, infinite rigidity in-plane in patches, infinite rigidity in-plane in patches with connecting belts of elastic slabs, and elastic slabs. As for the above four assumptions, they can be used according to the scale and complexity of the project and user's experiences, it would better use the least to get the best. One or combination of the above assumptions can be flexibly adopted in analysis of a building structure.

Its professional features are attractive. Some analysis and design parameters may be adjusted easily, and some special elements of building structures, such as frame-support-beam, tie beam, etc., are considered rationally. Section design of all elements of the building structure is done according to the design codes currently used in China (GBJ 10-89) or in British (BS8110). These features become the mark of SATWE, which is different from other finite element analysis programs. It has strong functions of pre- and post-processing. PMCAD is taken as the pre-processing program. All the geometric and loading information needed in SATWE is created automatically based on the structural database established in PMCAD. Information of multi-tower, stagger floor etc. can be generated automatically, and generalized-wall-elements and elastic-slab-elements can be divided further and condensed automatically by the program. All above features greatly simplify the operations of users. PK is taken as the post-processing program, when section design is done in SATWE, PK can be used to plot the working drawings of beams and columns. The combinations of internal forces of vertical elements at the ground floor can also be provided as the design loads of the foundation

3.3 CAD software for 2D Frame and shop drawings (PK)

It is applicable to various regular and complicated-shaped frame structure, frame-bent structure, bent structure, frame-wall structure simplified from shear wall and continuous beam structure in industrial and civil buildings. Suitable for following conditions: orthogonal or inclined connection of beams and columns, beams not in line in different stories, number of beams or columns not the same in different stories, columns with different heights in the first storey. hinged roof beam etc. Cantilever beam, bracket and secondary beam can be at arbitrary location of the frame. Beams of various shapes of cross-section (more than 10) , folded beam, beams with brackets , varied section beam and rectangular, circular, I-section columns as well as bent columns, various stirrups in columns can be plotted.

It has the function for calculating and checking of joint core, axial compression ratio of column, volume steel ratio of column can be performed based on the concepts of strong in columns and

weak in beams and strong in shear and weak in bent. Calculation for the elastic-plastic displacement of the weak storey under a seldom occurred earthquake, vertical seismic load and width of crack in beams can also be carried out.

The arrangement of reinforcement can be automatically given out based on the code and the detailing manual. The shop drawings of beams and columns can be plotted wholly or separately, or in the form of the table, where with functions of automatic selecting reinforcement, merge of sections in different storey or bay, automatic arrangement in a drawing.

3.4 CAD software for foundation (JCCAD)

Design calculation and reinforcement can be performed for independent foundation, strip foundation, elastic beam foundation, raft foundation and pile foundation. It can be interfaced with PMCAD, acquiring the data for axes of column array and arrangement of plan in the 1st storey of the structure, and also the loads on the foundation transmitting from the super-structure (PMCAD, SATWE, TAT and PK). Arrangement and modification of foundation can also be made with interactive interface. Based on the investigation data, a tectonic profile of the subsoil can be automatically plotted.

For foundation of beam-type, beam-plate type or raft foundation, the stress and reinforcement in the beam and raft are calculated based on the elastic foundation beam, and drawings of the plan and beams of the foundation can be plotted.

Optimum bearing layer for piles can be selected by means of interaction. Design can be performed for single pile, pile group and pile cap, including pre-cast pile and boring pile, and etc. A usual pile foundation data base is available. The calculation of pile foundation settlement under vertical loads and displacement under the horizontal load can be performed. Plan of pile foundation and working drawings of pile and pile cap can be plotted.

Pile-raft foundation is calculated by the finite element method based on MINDLN thick plate theory. The results include the displacements of piles and raft, the bending moments and shear forces on raft.By means of this program, calculation of box foundation of any irregular shape up to 3 stories and design of air-raid prevention projects of grade 5 and 6 can be performed and working drawings can be plotted. Structural design includes: based on the box foundation specification and air-raid prevention code, settlement and reaction of the foundation, bending of the whole foundation or part of the foundation and reinforcement can be calculated; internal forces in the wall, opening, linked and reinforcement can be calculated. The working drawings to be plotted include reinforcement of the upper and lower slab and walls in each storey and openings.

4 Architectural CAD software of PKPM (APM)

The 3-dimensional architectural design program APM is a CAD software designated for schematic design of architectures and plotting working drawing of building plan, elevation, section and perspective. It is one of the programs in PKPM series CAD software.

Designers always hope that architectural design and structural design are linked by means of computer, and the data of both phases can be shared, i.e., data of architectural design can be adopted in structural design and data of structural design can also be transformed to the data used in architectural design. Besides, the phases of work should be done in the same graphic supporting environment. Based on these

ideas, and on the PKPM series CAD software for structural design, architectural design software, APM, has been developed successfully, which enhances both of the architectural and structural design in an integrated CAD system.

The animation, rendering, hiding of building model can be given in APM. It also supplies shop drawing of building plan, elevation and section together with architectural schematic design. The creation of shop drawings is based on combination of hiding and data analysis. The data of APM can be transformed to the following structural design, which greatly simplifies the structure data inputting. Firstly, array axes, axes, and arrangement of columns, walls and openings in architectural design can form the basic skeleton of structural layout. Secondly, the information of materials, details, and filler walls can create the load information for structural design.

5 References

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